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Development of methods of Producing Large Areas of Silicon Sheet by the slicing of Silicon Ingots using Inside Diameter (I.D.) Saws.

FIRST QUARTERLY REPORT

May 1 - June, 1979

Prepared by

Peter Aharonyan

JPL Contract No. 955131

SILICON TECHNOLOGY CORPORATION
48 Spruce Street
Oakland, New Jersey 07436

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ABSTRACT

The objective of this contract is to develop methods of producing large areas of silicon sheets by slicing silicon ingots using inside diameter (I.D.) saws.

An STC 16 inch automated I.D. slicing machine (Model SMA-4401) is being used for this effort. The saw has been modified to accept an STC Programmable electric feed system, STC Crystal Rotating System and an STC Dyna-Track Blade Monitoring and Control System. The saw and accessories will be used to slice 100mm diameter single crystal silicon ingots while rotating them. The automated saw will automatically recover the wafers and load them into a cassette.

The amount of material lost during slicing is being reduced by using smaller blades than ones normally used to slice 100mm wafers. Some blades have been manufactured with cutting edge thickness as low as 0.20mm. Initial slicing runs on 75mm diameter silicon has been successful on blades in the 0.23 to 0.24mm cutting edge thickness range. The thinner blades will be used to slice 100mm silicon while rotating the boule.

1.0 INTRODUCTION

Most silicon wafers are presently being produced by slicing single crystal silicon on Inner Diameter (I.D.) slicing machines.

The objective of this contract is to develop techniques for I.D. slicing that can reduce the add-on cost and also reduce the amount of material that is being lost due to "Kerf", (material lost by the grinding action of the I.D. diamond blade). Present plans are to develop these techniques for 100mm diameter silicon however, the economics of crystal growing may require slicing capability for larger diameter silicon. The methods may be further developed in the future for larger diameter silicon.

Present technology requires the use of a 22 inch diameter blade to slice 100mm diameter ingots and a 16 inch blade to slice 75mm and smaller diameters. Since the I.D. blade is tensioned around the periphery, the larger size blades must have a thicker body or core to maintain the same rigid cutting edge as the smaller blades which increase the cutting edge thickness and the amount of silicon lost during slicing. One of the methods for slicing developed under this contract will involve the rotation of the silicon crystal during slicing. Advantages from this technique are reduced entry of the blade into the crystal which permits the use of a smaller blade, and a theoretical single point contact between the crystal and the blade which may reduce blade wander allowing the use of a thinner cutting edge. Initial work done on rotational slicing of Gadolinium Gallium Garnet for bubble memory substrates indicates similar results.

The 16 inch I.D. blades normally have a cutting edge

thickness of 0.26 to 0.33 mm. The cutting edge thickness may be reduced by controlling the plating of the diamonds to the I.D. The thinner blades must be more tightly controlled during slicing to minimize rubbing of the core with the wafer or the crystal, since the clearance between the cutting edge and the core are reduced. Normally 16-inch blades are manufactured from 0.105 mm thick stainless sheets.

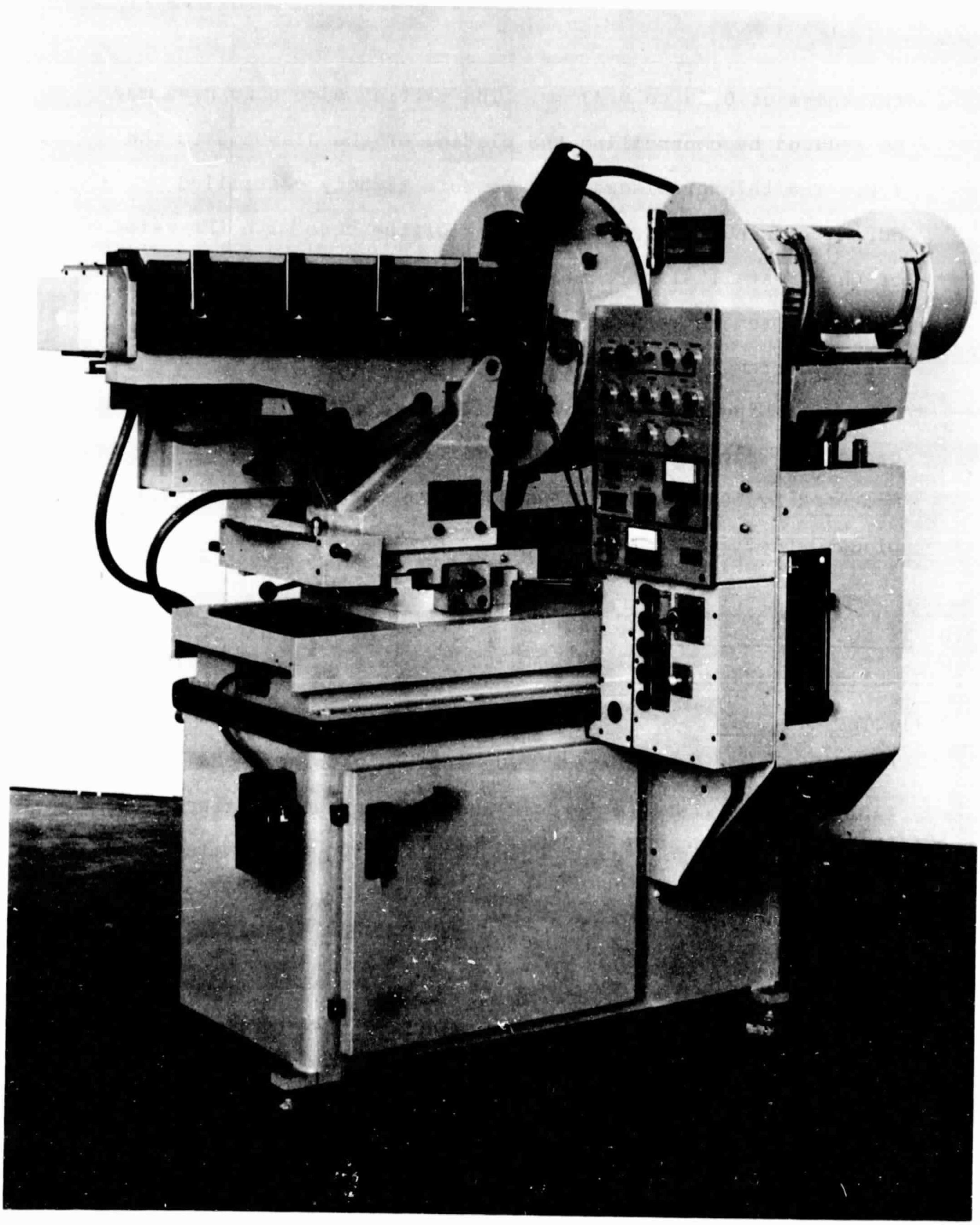
Rubbing the core can dramatically reduce blade life and can cause wafer breakage during slicing. Blade performance as measured by blade wander is monitored using an STC Dyna-Track blade deflection system to correct any blade problems.

2.0 TECHNICAL DISCUSSION

2.10 Slicing Equipment

2.11 The I.D. Saw

A 16-inch automated I.D. slicing machine (Model SMA-4401) was installed to perform the work on this contract. Normally, a 22-inch saw is used to slice 100 mm diameter silicon, however, Kerf loss is generally 0.06 - 0.12 mm greater due to the need to use a thicker core for the larter blades. The largest diameter silicon that a 16-inch blade can slice is approximately 80 mm. The limitation is caused by the distance from the cutting edge on the I.D. to the O.D., where the blade meets the blade mount. If the boule is rotated during slicing, the effective cutting distance is reduced to one-half the diameter of the silicon ingot, allowing the use of a smaller blade. There are no modifications required to the slicing machine to accept the Crystal Rotating Fixture.



STC I.D. SLICING MACHINE

There have been some modifications made to the saw to accept an STC programmable Electric Feed System to allow changing feed rates during the cutting stroke. An STC Dyna-Track Blade Monitoring System has also been added to record blade durations during slicing runs.

2.12 Crystal Rotating System

The Crystal Rotating System has a precision spindle and gear motor integral with the mounting block; fits into ingot box in normal spring loaded manner. Gear motor provides full torque at all speeds, with speed regulation better than 1% of set speed over full load variation.

The crystal can be rotated from .15 to 150 RPM in CW or CCW direction.

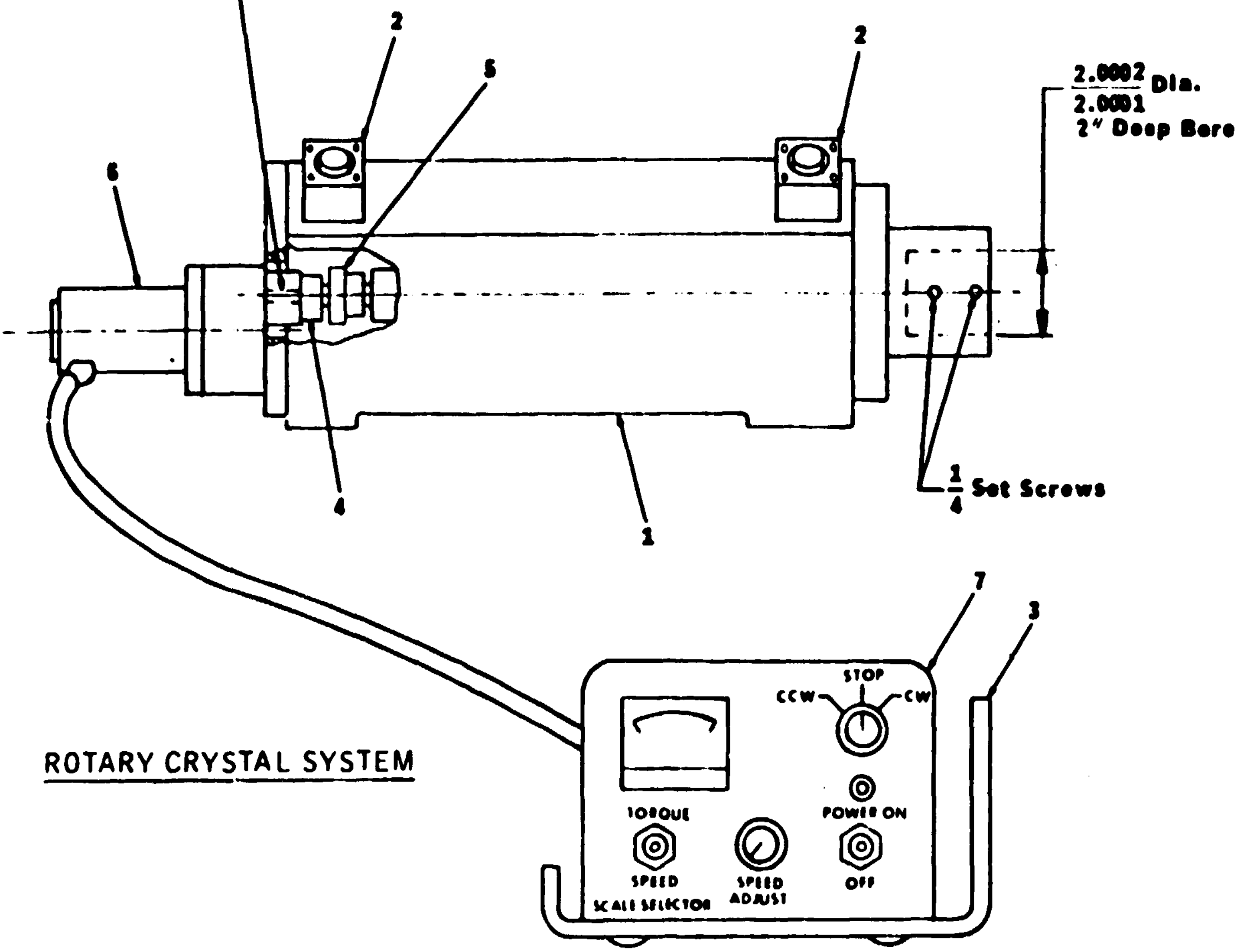
The capacity is up to 5" diameter, with crystal length up to 16 inches.

Rotation rate can be programmed with a preshaped cam or can be set manually.

2.13 Electric Feed Actuator System

This system is an electro-mechanical closed loop servo system. Actuation is provided by a 1/8 H.P., D.C. gear motor driving a precision lead screw and nut assembly. The feed rate may be set manually or varied by the preprogrammed shape of a cam.

Cutting speed is infinitely variable from 0.5 to 35 mm per minute. Speed regulation is 1% of set speed or better. The preprogrammed cam can be shaped to suit. There is an overload slip coupling protection. The sealed drive train

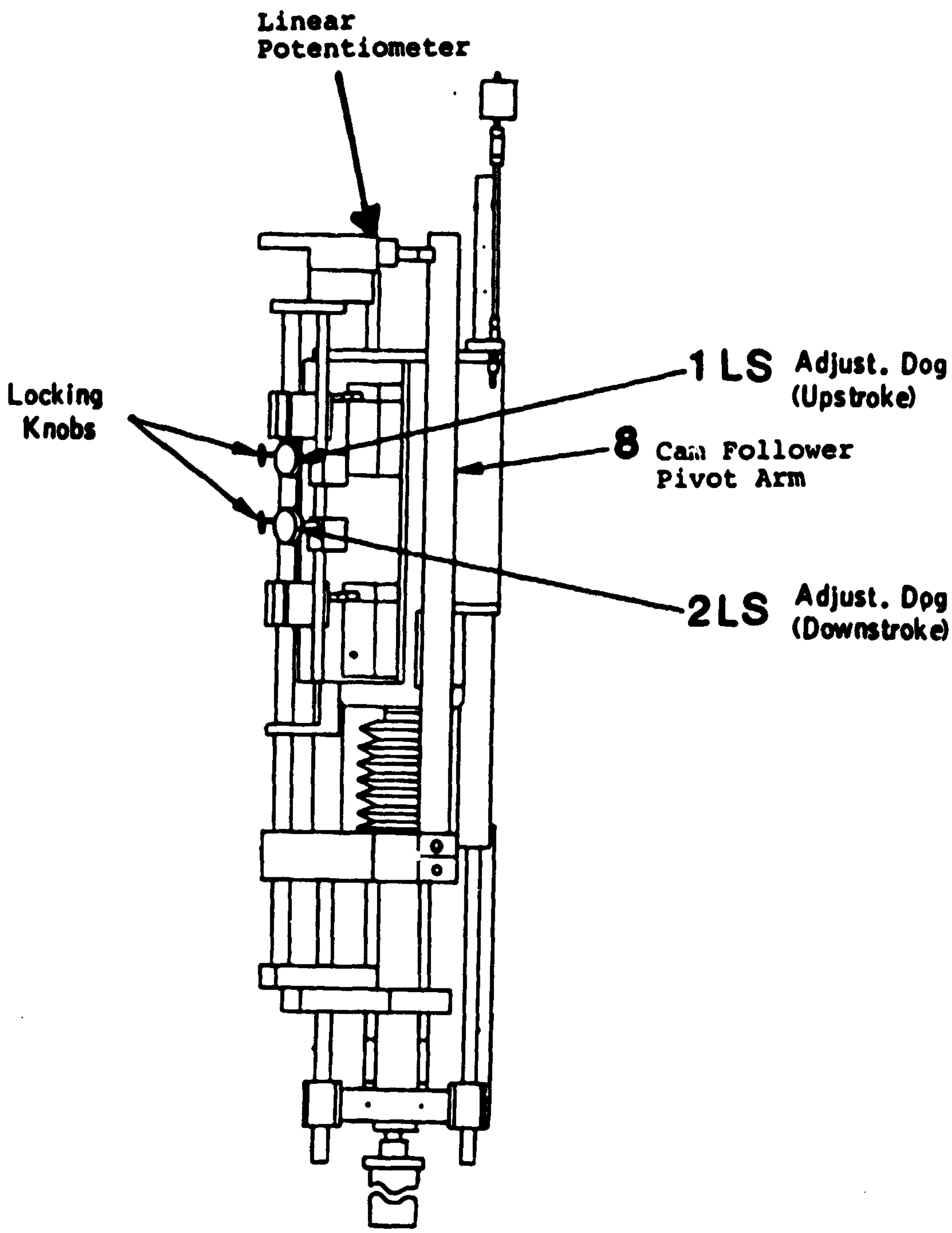


ROTARY CRYSTAL SYSTEM

Item	Description
1	Rotary Crystal Assembly
2	Plunger Assembly
3	Controller Mounting Bracket
4	Slip Clutch
5	Coupling Assembly
6	Motor
7	Motomatic Control

PROGRAMMABLE FEED SYSTEM

ELECTRIC PART NO. SEA 4302



FRONT VIEW

is drip oiler lubricated.

The unit can be retrofitted to a standard machine. Controls include constant feed rate adjustment and minimum and maximum programmed rate. The unit can be run in the manual or programmed mode, by means of a toggle switch.

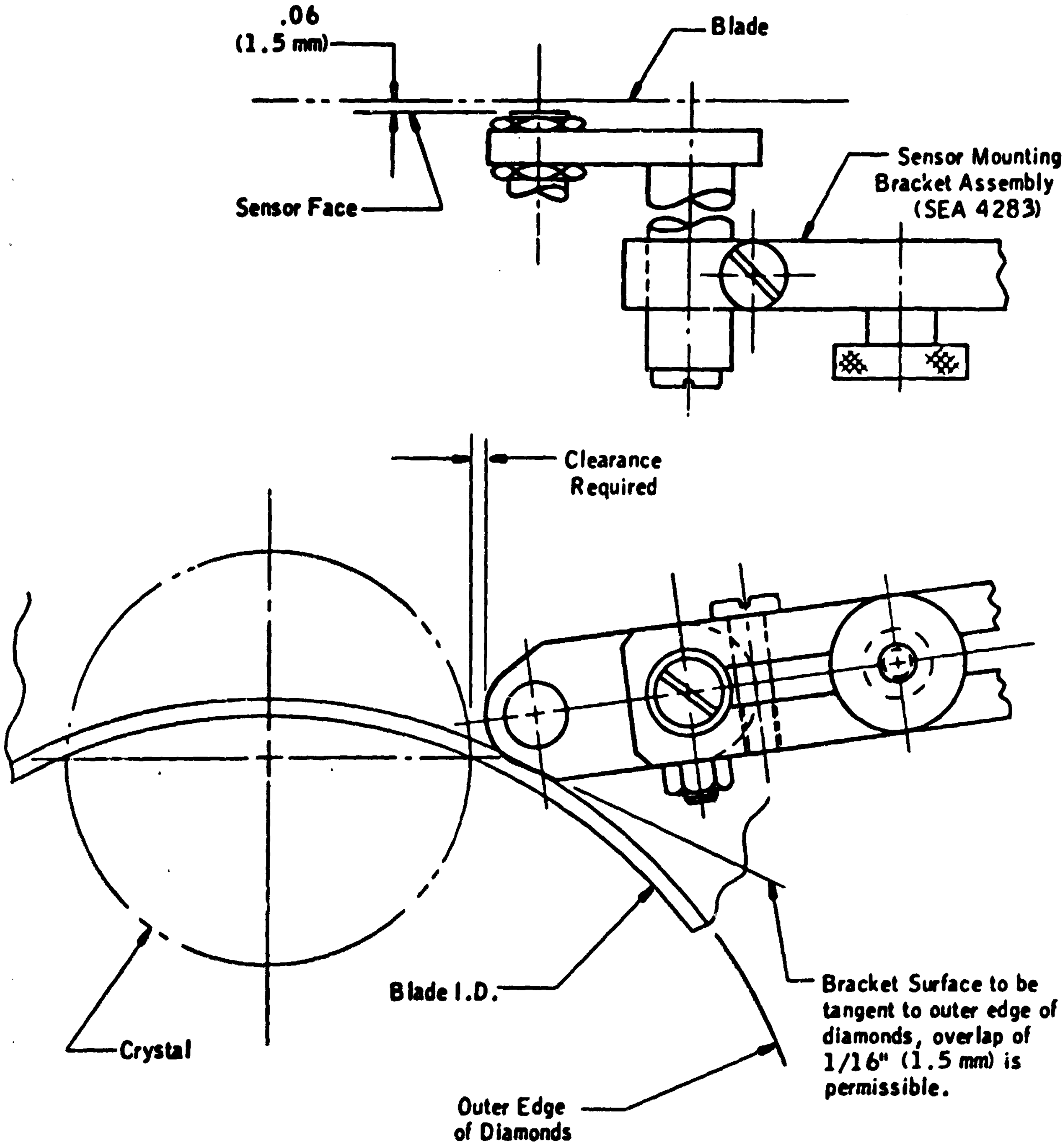
There is also a cam to control the rotation of the Crystal Rotation System.

The feed rate is proportional to the displacement of a linear transducer in the programmed mode.

2.14 Blade Monitoring System

The Blade Monitoring System continuously measures and records lateral runout of the cutting edge of the I.D. diamond blade to the nearest 0.0001 inch while slicing. Axial, or lateral, deflection of the cutting edge of an I.D. diamond blade is a major cause of work damaged silicon wafers. The problem can usually be easily corrected by dressing one or both sides of the blade. The monitoring system signals when the blade should be dressed and on which side. The system will also indicate when a blade requires tensioning.

The system consists of a highly accurate, non-contact deflection gauge, a strip chart recorder and an analog meter with plus/minus limit settings. Mounted on the STC machine head, the non-contact gauge continuously senses the axial deflection of the blade I.D. during slicing. The information is



DYNATRACK SENSOR ALIGNMENT

recorded on the trip chart, and displayed on the analog meter to the nearest 0.0001 inch (2.5 microns). The strip chart travels at a rate of 4 inches per hour. The plus/minus settings can be used to halt machine operation if they are exceeded.

2.20 Blade Development

Several approaches have been tried in the design of a thinner cutting edge for the STC 16-inch I.D. diamond blade for this contract.

Two blades were manufactured with a cutting edge thickness of 0.23 to 0.24 mm by initially plating the blades to a thickness of 0.29 to 0.30 mm, and subsequently grinding the cutting edge to the desired thickness on an external fixture. The initial high plating thickness provided diamond build up from the I.D. of approximately 0.20 mm (Standaod Double Plated blades have a diamond build up of approximately 0.25 mm). Diamond build up is an important factor in blade life, since diamonds are worn away from the I.D. as a blade is used during slicing.

We have also manufactured several blades with cutting edge thicknesses ranging from 0.20 to 0.24 mm by reducing the plating time on our standard single plated blade manufacturing operation. We are able to routinely control the blade thickness down to 0.20 mm using standard 325-400 U.S. mesh diamond

BLADE TESTS

BLADE NO.	CORE	THICKNESS	BUILDUP	TYPE
1	0.004"	0.0090-0.0095"	0.008"	Ground
2	0.004"	0.0095-0.0100"	0.009"	Ground
3	0.004"	0.008"	0.006"	Single Plated
4	0.004"	0.0090-0.0095"	0.007"	Single Plated
5	0.004"	0.0085-0.0090"	0.007"	Single Plated
6	0.004"	0.0090-0.0095"	0.007"	Double Plated

particles. Although blades can be manufactured using smaller diamonds, blade performance begins to degrade with a decrease in particle size. Earlier attempts to manufacture blades with 500 U.S. mesh diamonds have demonstrated this ralationship. Several blades have also been manufactured using our standard double plating operation, with diamond build up approaching that of standard blade (0.20 - 0.23 mm) and thickness in the 0.23 - 0.24 mm range.

2.30 Process Development

The blades were tested on 76mm diameter Single Crystal Silicon Ingots (1-0-0) P-type.

The cutting speeds were maintained at approximately 1 inch/ min., since this is the expected speed at which 100mm silicon will be sliced during the rotation experiments. Cutting performance was monitored using the STC Dyna-Track Blade Monitoring System.

The Vacuum Wafer Recovery System was also tested during these runs.

Best performance was achieved on blades with cutting edge thickness of 0.24 mm, and minimal amount of grinding of the cutting edge..

The two initial blades which had been extensively ground would not cut without constant correction of the cutting edge by dressing. These blades began to rub the core against the wafer from the beginning of the slicing runs. Blade deflection

was not excessive; however, there was a tendency for a positive bow. (Positive bow means that the face of the crystal has a convex shape cut into it, or that the blade is moving away from the crystal as it approaches the center). Although the bow was not excessive (5 - 13 mm) the pattern on the chart recorder measuring bow was erratic and the wafers were breaking. A second problem which became apparent was the excessive amount of heat being generated during slicing. This was evidenced by heat discoloration of the stainless steel core around the I.D.

We think that extensive grinding of the cutting edge fractures many of the diamond particles, causing them to lose their blocky shape. This in turn lowers the efficiency with which the blade is slicing. Grinding the edge may also be weakening it, and further reducing the rigidity of the cutting edge. The loss of a good cutting edge will cause higher than normal cutting pressures, causing excessive blade wander and excessive heat since the diamonds are not cutting freely. The effect is similar to a grinding wheel that needs dressing. Once the core of the blade has been rubbed by the wafer, or there has been sufficient heat generated to discolor the core, it will begin to lose tension. After this damage has occurred, it is nearly impossible to correct the blade by dressing.

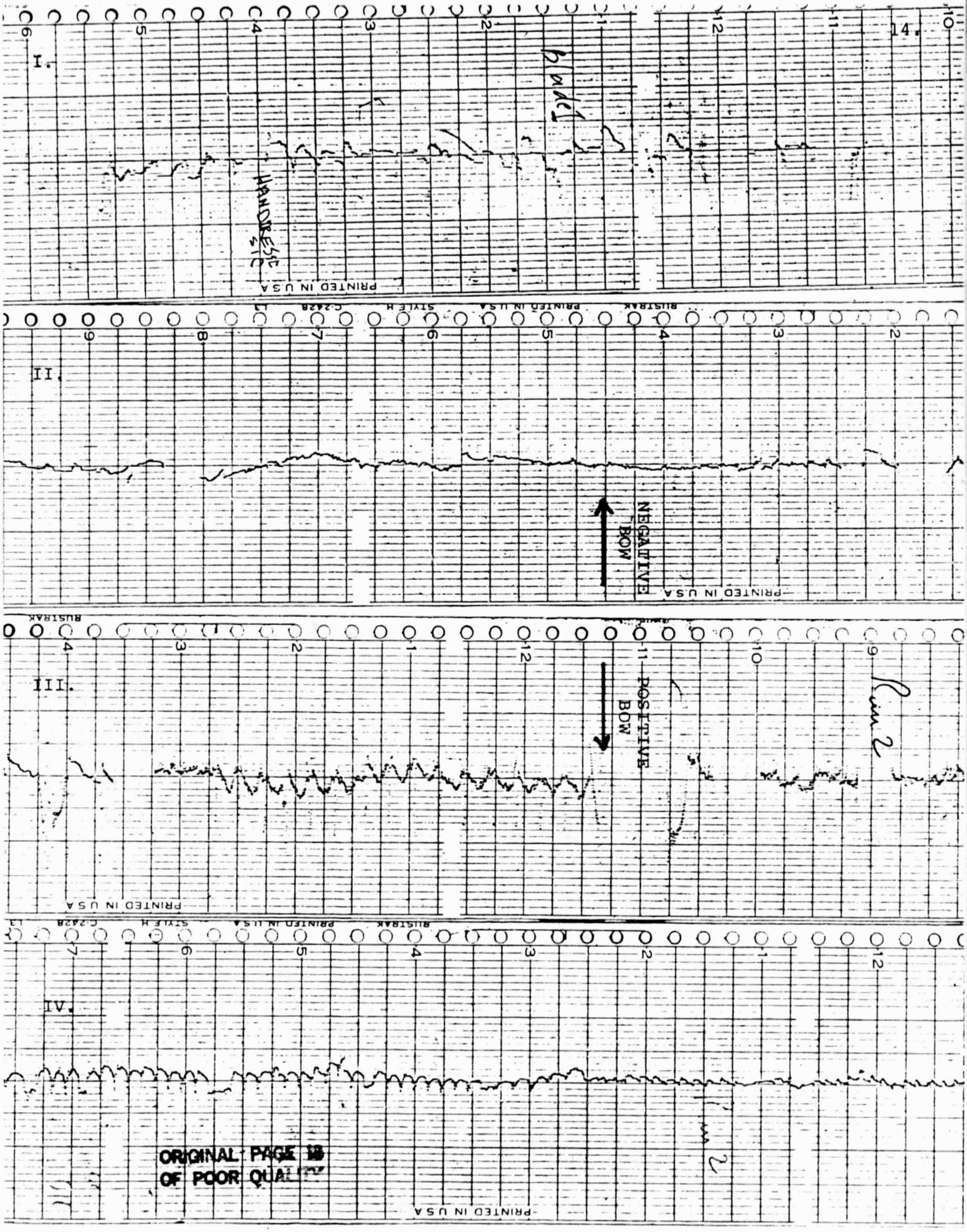
The chart recordings made with the STC Blade Monitoring System also showed the effects of a poor cutting blade. Typically, when a blade is not cutting properly, the chart recorder will show an erratic pattern with a tendency for a positive bow. When the blade is cutting well, the chart recorder will exhibit a

regular negative bow pattern. A good slicing range was found to be between 0 to 10 um negative bow.

The thinner blades do not allow as much wander as thicker blades. Typically, the blades had to be dressed every 20-30 slices (about twice as frequently as standard blades) to keep blade wander under 10 um.

The Blade Monitoring traces show typical slicing problems. Traces I, II and III are erratic. Although Trace II does not show much deviation, the pattern is erratic. We experienced problems during that run. Trace IV shows a good slicing run. The pattern is even and shows a regular negative bow of about 5 microns.

A regular negative bow in this range gave the best results. A regular positive bow also performed well; however, we could not exceed 8 microns positive bow before we began to experience problems.



SLICING DEFLECTION TRACES

SLICING RESULTS

BLADE #	RUN #	AVERAGE SLICE THICKNESS (Mils)	TOTAL SLICE TO SLICE THICKNESS VARIATION	AV. BOW (Microns)
1	1	15.2	.6	8
1	2	19.4	.5	8
2	3	17.3	.5	17
3	4	21.4	1.5	15
4	5	14.8	.5	3
4	6	11.3	.9	10
5	7	14.2	.6	14
5	8	13.9	.3	8
6	9	11.7	.5	8
6	10	9.2	.4	12

3.0 Conclusions

Blades can be manufactured as thin as 0.20 mm, using standard plating techniques and standard diamond sizes. Three techniques available are:

1) Grinding of the cutting edge
2) Controlled single plating
3) Controlled double plating

The thinnest blades are made with a single plating oepration; however, they do not provide the life of the double plated blades. Double plated blades have a minimum thickness of 0.23 to 0.24 mm.

When thicker blades are ground excessively, they do not cut as freely as unground blades.

The thinner cutting edges require more frequent dressing to keep the blade from wandering excessively. Such wander causes the blade cores to rub, thereby reducing tension.

Blade performance should be measured by the amount of axial deviation of the cutting edge. Continuous monitoring is preferable, since it predicts problems. We were able to keep yields over 90% using this technique.

4.0 Recommendations

We recommend that additional work be done in blade development to reduce kerf loss. Present minimum core thickness is 0.10 mm (4 mils). It may be possible to reduce this to 0.076 mm (3 mils). The additional gap between the diamonds and the core will allow greater deflection without the need for dressing. The thinner material will be weaker; however, if higher tensile strength steel is obtainable, this reduction may be possible without weakening the blade.

Machine controls may be automated if information from the deflection system is used to perform functions such as dressing.

5.0 New Technology

No new technology was developed during this quarter.

6.0 Work Planned for Next Quarter.

The rotating fixture will be run, using 75 to 100 mm diameter silicon ingots. The programmable feed system will be used in conjunction with the rotary crystal system to arrive at some optimum programs for rotational slicing of 100 mm diameter silicon.

The thinner blades manufactured during the first quarter will be used in conjunction with the rotary crystal system to reduce kerf loss.

We will experiment with blades ranging in thickness from 0.20 to 0.24 mm to determine minimum blade thicknesses that yield acceptable results.

The Single Slice Recovery System will be used to recover the wafers after they have been sliced and to load the wafers into a cassette.

We will also determine the availability of thinner core materials to manufacture low kerf I.D. blades.

PROGRAM PLAN

DRD No. 88 DRL No. SC

Month (1979)